Engineering Note for

E-906 Tube Assembly

Project: E906, P-25 (LANL)

Title: E-906

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Date: 2/2012

Reviewers: Walt Sondheim, P-25, Los Alamos National Laboratory

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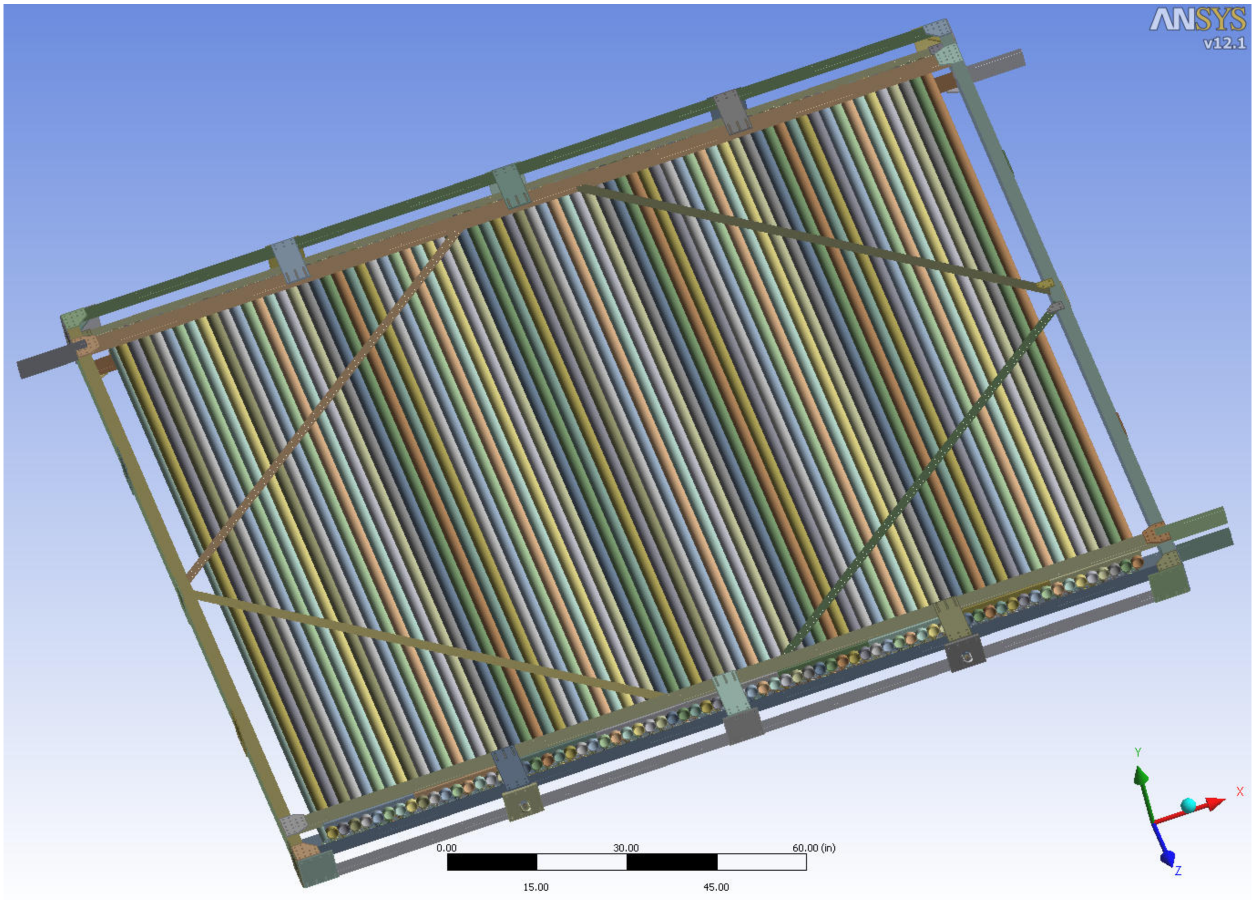
ABSTRACT:

The following calculation note pertains to the E-906 Prop Tube Assembly, as developed by Ming Liu and Walt Sondheim. These calculations describe the ability of the Tube Assembly to handle service and handling loads. Areas of concern are noted herein.

DESIGN:

Two rows of tubes are nested one on top of the other, but staggered. A bead of glue is placed longitudinally at the tube to tube interface. This glue will provide additional structural support, but is hard to quantify. Thus, it will not be relied upon.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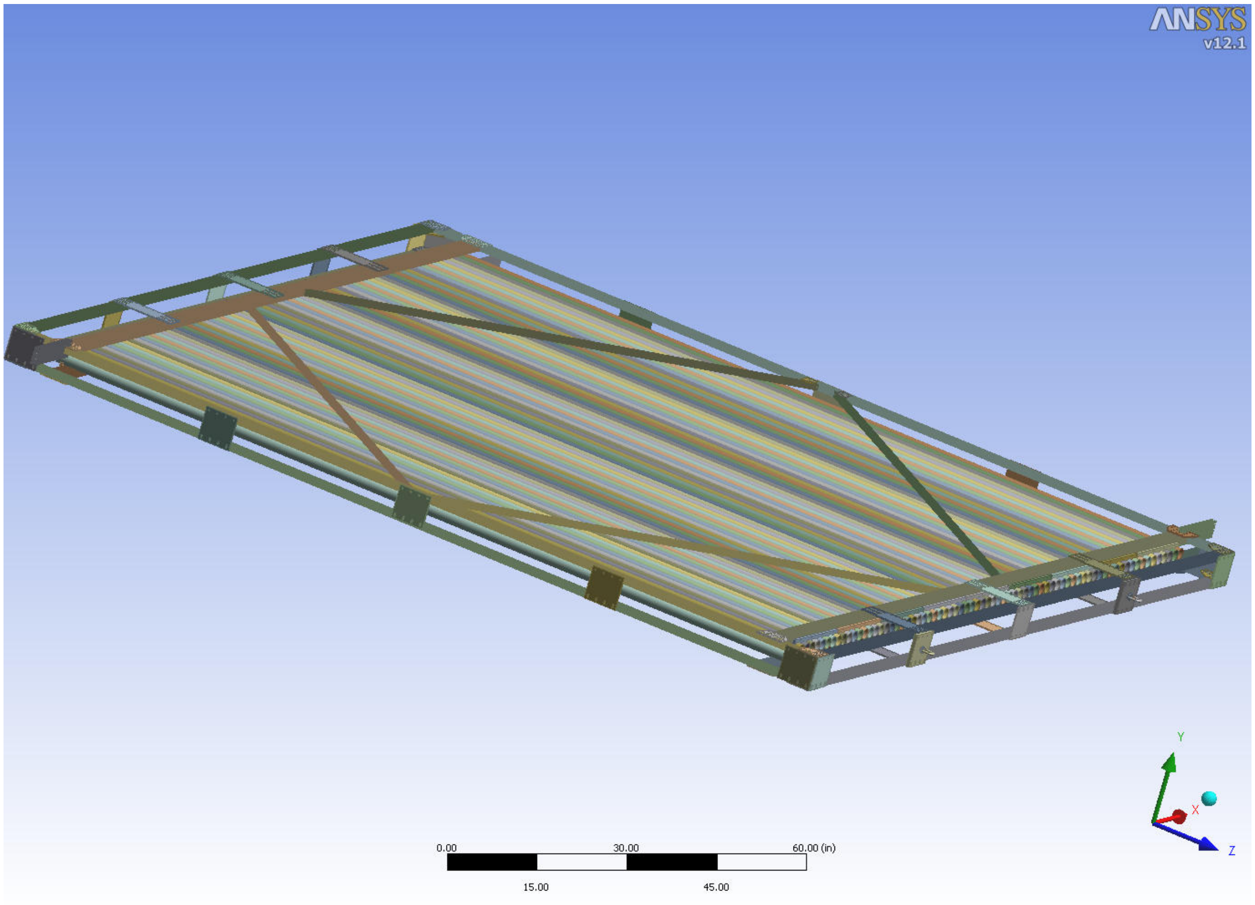


ANALYSIS

The analysis is grouped into individual calculations. Stresses are calculated for various components, and those stresses are compared to allowable stresses based upon the materials used. **Confirmation that the as constructed 4X and 4Y frames are consistent with the following analysis is required. Some construction occurred at LANL and other portions of the construction occurred elsewhere.**

FORMULAS AND MATERIAL ALLOWABLES

Refer to the Appendix in "Mechanical Engineering Design", 4th Edition, Shigley and Mitchell, for maximum moment, stress, and deflection formulas. Refer to Appendix C, "Mechanics of Materials", Second Edition, Gere and Timoshenko for formula and explanation of the parallel axis theorem.

The frame is composed primarily of 80/20 Inc. brand extruded aluminum beams. Plates used to join the 80/20 Inc. beams are also produced by 80/20 Inc.

Aluminum allowable stresses are obtained from the Aluminum Design Manual published by the Aluminum Association. Part I-A, Table 3.3-1 lists the 6061-T6 minimum tensile ultimate stress as 38 ksi, and the minimum tensile yield stress as 35 ksi. Part I-A, Section 1.3 describes safety factors to be applied. Bridge type structure safety factors are used. The allowable tensile stress is the lesser of the minimum yield strength divided by a factor of safety of 1.65, or the minimum ultimate tensile strength divided by a factor of safety of 1.95. Thus, an allowable tensile stress of 19,487 ksi shall be used herein. The allowable shear stress is calculated using the Aluminum Design Manual Part 1-A, Section 3.4.20, where $F_s=(F_{ty}/1.732)/n_y$. The value for n_y is obtained from Table 3.4-1 and is 1.65. The allowable shear stress is then 12,247 psi.

Part I-A Table 3.3-1 lists the minimum compressive yield as 24 ksi.

1010, 1020, and 1030 members are made from 6105-T5. The Aluminum Design Manual Part 1-A, Table 3.3-1 lists the 6105-T5 minimum tensile ultimate stress as 38 ksi, and the minimum tensile yield stress as 35 ksi. Part I-A, Section 1.3 describes safety factors to be applied. Bridge type structure safety factors are used. The allowable tensile stress is the lesser of the minimum yield strength divided by a factor of safety of 1.65, or the minimum ultimate tensile strength divided by a factor of safety of 1.95. Thus, an allowable tensile stress of 19,487 psi shall be used herein.

The 80/20 Inc. joining plates are also made from 6105-T5 material. Accordingly, the allowable tensile stress for these parts is also 19,487 psi. The allowable shear stress is calculated using the Aluminum Design Manual Part 1-A, Section 3.4.20, where $F_s=(F_{ty}/1.732)/n_y$. The value for n_y is obtained from Table 3.4-1 and is 1.65. The allowable shear stress is then 12,247 psi. See Calculation #9 below which addresses joining plate screw strength.

The AISC Manual of Steel Construction is used to determine allowable tensile and shear stress for the fasteners. The allowable tensile stress is taken as 1/3 of the minimum ultimate tensile stress. The allowable shear stress is taken as 0.17 times the minimum ultimate tensile strength, when threads are included in the shear plane. The fasteners used for the frame construction are Alloy 4037 quenched and tempered steel according to the manufacturer. The ultimate tensile strength of this material is 101,000 psi. Consequently, the allowable tensile stress is 33,650 psi. The allowable shear stress is 17,170 psi.

Stainless steel fasteners are used between the scalloped strip and G-10 strip. These parts are used distribute loads between the prop tubes and the frame. The yield strength of these stainless steel screws is taken as 30,000 psi. The allowable stress will be taken as 15,000 psi.

Calculation # 1 – Weight and Tube Strength

Analyze the one tube alone to determine if it can support its own weight, simply supported at the ends.

Calculate weight of tube,

d_{outer} = 2.00 in.

d_{inner}= 1.93 in.

$t_{tube\ wall}$ = 0.035 in.

$Weight_{single\ tube}$ = (cross sectional area)(length)(density)

$Area_{tube\ cross\ section} = \pi\ [(1.0\ in.)^2 - (0.965\ in.)^2] = 0.2161\ in.^2$

$Density_{aluminum} = 0.1\ lb/in.^3$

Length = 144 in.

$Weight_{single\ tube}$ = 3.11 lb

$Weight_{single\ tube}$/length= 0.0216 lb/in

$I_{single\ tube} = \pi\ [(d_{outer})^4 - (d_{inner})^4] / 64 = 0.1043\ in.^4$

Maximum moment for a simply supported beam with a distributed load is

$M_{max} = (w\ l^2)/8 = 56$ in-lb

w = 3.11 lb/144 in. = 0.0216 lb/in.

l = length = 144 in.

$\sigma_{max} = M\ c/I = (56\ in\text{-}lb)(1.00\ in.)/0.1043\ in.^4 = 537$ psi

c = tube radius = 1.00 in.

$\delta_{max} = (5wl^4)/(384EI) = 0.12$ in.

$E_{aluminum}$ = 10,000,000 psi

Tubes are aluminum 6061-T6. The calculated stress is well below the 19,487 psi allowable tensile stress and is therefore acceptable. Deflection is small. Stress is also low enough so that local tube wall buckling should not be a concern. Glued joints not taken credit for, and ends are clamped by the scalloped pieces. Thus, tubes individually are acceptable.

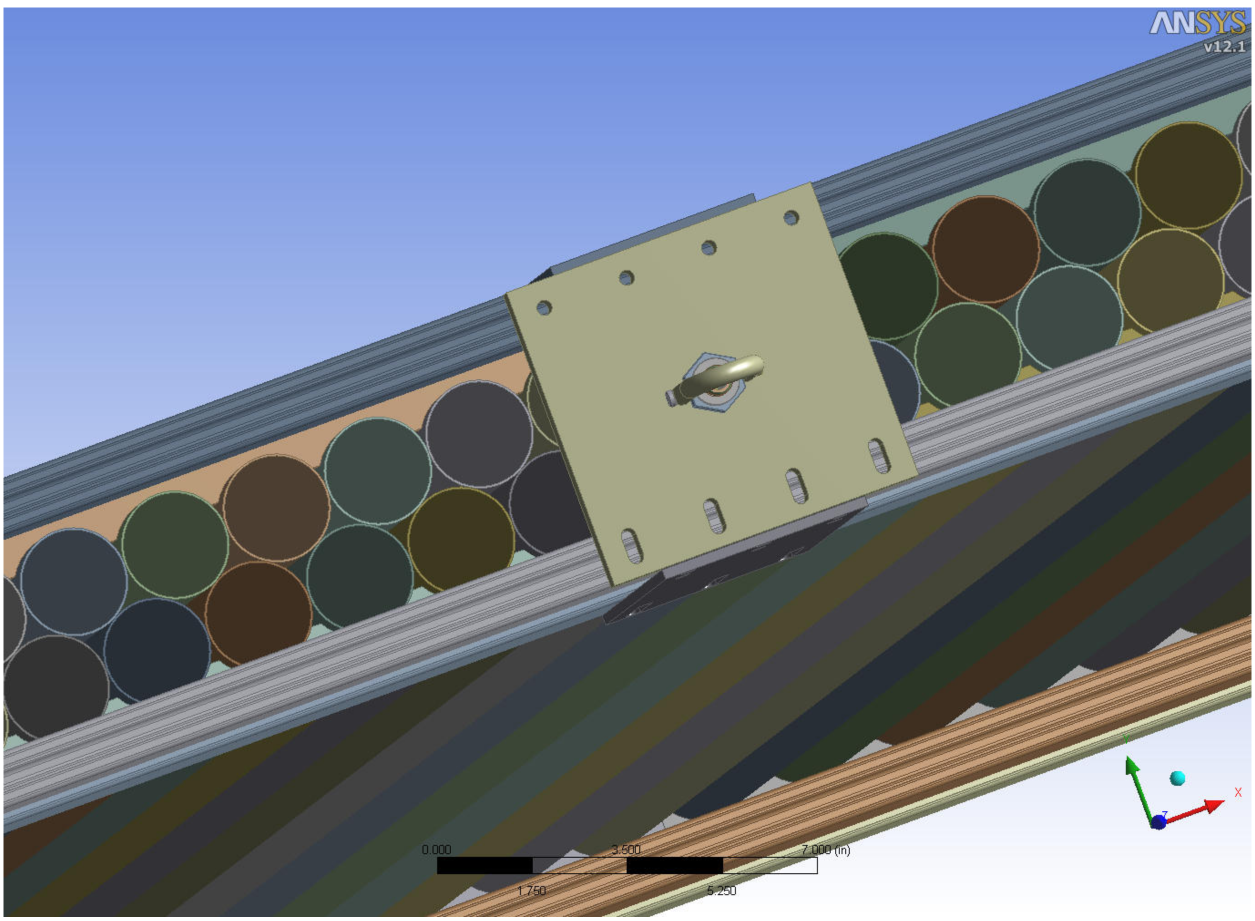
Calculation # 2 – Weight of Tube Array

Calculate weight of tube array. Each tube weighs 3.11 lb, and there are 144 tubes. Thus total tube weight is 450 lb. Add 10% for glue. For analysis purposes, use:

$\text{Weight}_{\text{tube array}}$ = (450 lb)1.1 = 495 lb

Weight of the structural members must be considered. Use a total weight (tubes and structural frame) of 700 lb.

Calculation # 3 – Strength of Lifting Features



Frame in vertical position (tube axes perpendicular to floor)

A lifting plate and swivel hoist ring will be used at each corner. The plate will be 5/8 inch thick and made from 6061-T6. A Carr-Lane swivel hoist ring (CL-1000-SHR-1) with a 1000 lb capacity will be mounted to the plate. The swivel hoist ring bolt is 0.54 inches long, and the plate is 0.625 inches thick, so sufficient engagement exists. Calculate thread shear stress in the mounting plate (frame in upright position).

$A_{\text{shear, 5/8'' threads in the hoist ring mounting plate}} = \pi(5/8 \text{ in.})(0.625 \text{ in.})(1/2) = 0.61 \text{ in.}^2$

$\tau = V/A_{\text{5/8'' threads in the hoist ring mounting plate}} = (1000 \text{ lb})/0.61 \text{ in.}^2 = 1{,}640 \text{ psi}$

The allowable shear stress of 6061-T6 is 12,247 psi. Shear stress calculated above is acceptable.

Check tensile strength of eight fasteners which secure the plate to the frame. Use actual load of 350 lb (700 lb frame weight divided amongst two hoist rings).

$A_{\text{tensile, 1/4'' screw}} = 0.0318 \text{ in.}^2$

$\sigma_{\text{0.25''hoist ring plate screws}} = F/A = 350 \text{ lb}/(8(0.0318 \text{ in.}^2)) = 1{,}376 \text{ psi}$

$F_{\text{screw}} = 350 \text{ lb} / 8 = 44 \text{ lb}$

The allowable tensile stress for the fasteners is 33,650 psi. Also, refer to Calculation #9 below. Vendor does not cite an allowable tensile load for the screws using the 80/20 nuts. **The tensile pull out strength needs to be ascertained through testing, etc.**

If stainless steel screws are assumed with a 30,000 psi yield strength, a factor of safety of three would dictate a 10,000 psi tensile stress allowable. Calculated stress is well within this limit.

Frame in horizontal position (tube axes parallel to floor)

This arrangement requires the two hoist rings to carry only half of the 700 lb load, or 175 lb per hoist ring.

The plate is secured to the frame with eight 0.25 inch diameter screws. Check shear strength of screws.

$A_{\text{shear, 1/4'' screw}} = 0.0269 \text{ in.}^2$

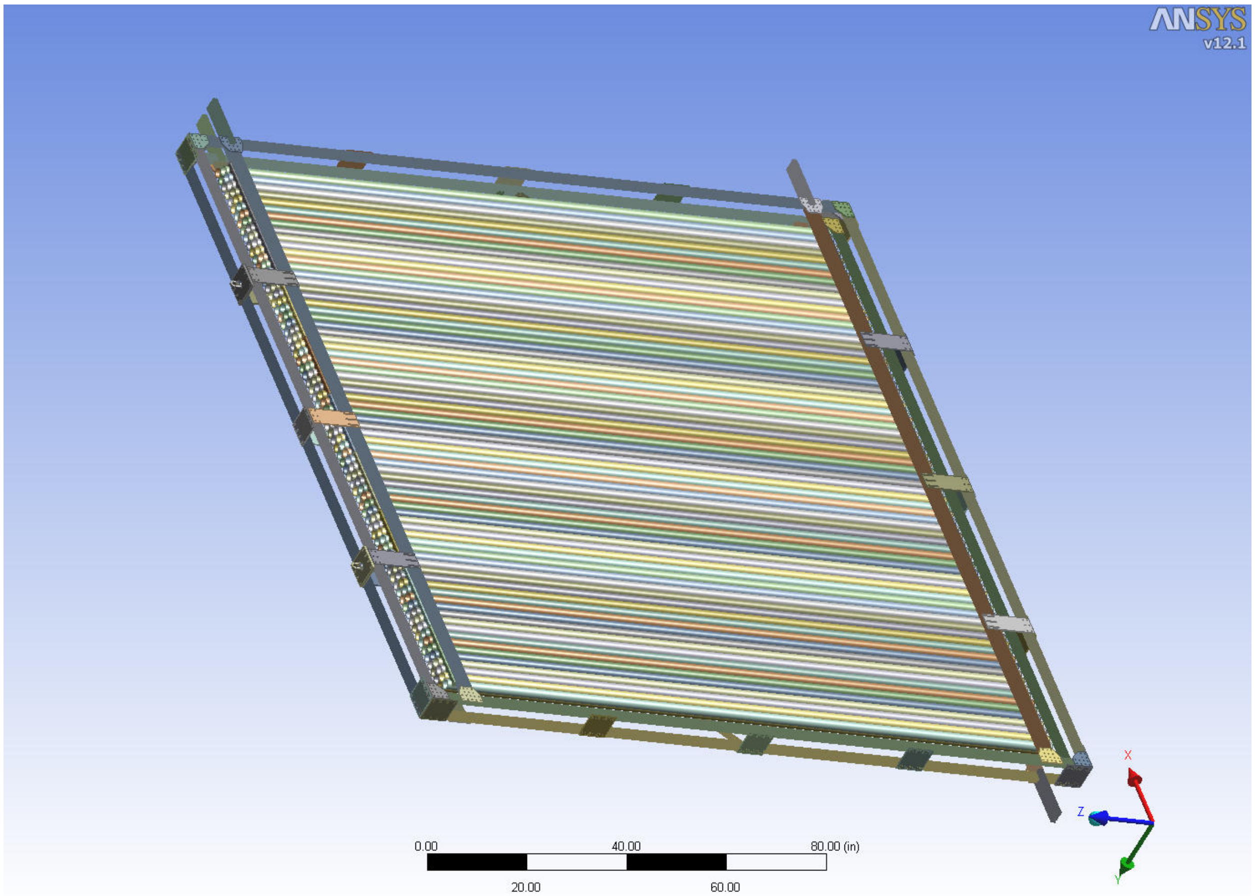
$\tau = V/A_{\text{shear, eight 1/4'' screw}} = (175 \text{ lb})/(8(0.0269 \text{ in.}^2)) = 813 \text{ psi}$

$V_{\text{screw}} = 175 \text{ lb} / 8 = 22 \text{ lb}$

The vendor listed allowable shear force on the ¼ -20 screws is 175 lb. Refer to Calculation #9, and vendor data at end of report. If stainless steel screws are assumed with a 30,000 psi yield strength, a factor of safety of three would dictate a 10,000 psi tensile stress allowable, and a 5,000 psi shear allowable. Calculated stress is well within this limit.

Calculation # 4 – Stresses in 4X and 4Y Frames Due To Lifting

The frame may be lifted from the horizontal position (frame parallel to floor) into the vertical position.



Frame in horizontal position (tube axes parallel to floor)

The frame would be supported along two opposite edges of the frame. Total frame weight is estimated at 700 lb. This will be a distributed load between the two supported ends. Maximum bending moment will occur between the supported ends.

$M_{midspan} = wL^2/8$ or $FL/8$

Where:

L=length of span

w = distributed load = 700 lb/152 in. = 4.6 lb/in.

F = total load = wL

$M_{midspan}$ = (700 lb)(152 inches)/8 = 13,300 in-lb

Need to take credit for both top and bottom layers of 1020 structural members. This will mean that shear must be transmitted effectively between top and bottom layers. Check bending stress for situation where top and bottom 1020 layers participate. Use parallel axis theorem to calculate net moment of inertia ($I_x = I_{xc} + Ad_1^2$). Refer to included vendor data attached.

I_{total} = 2(0.0833 in.^{4}) + 2(0.7914 in.^{2})(2 in.)^2 = 6.5 in.^{4}

σ_{max} = M c/I = (13,300 in-lb)(2.5in.)/6.5 in.^{4} = 5,116 psi

The allowable tensile stress is 19,487 psi for the 6105-T5 1020 members. Consequently, the calculated stress is acceptable.

Maximum deflection is calculated as follows.

$Y_{max} = 5wL^4/(384\ EI)$ = 0.5 in.

E = 10,000,000 psi for aluminum

No credit is taken for the tubes. Actual deflection will be less than this.

Maximum shear load occurs at each supported end, and is equal to 700 lb/2. Shear will be carried on either side of the frame, so each side must carry 175 lb. Strap plates are 5.75 in. x 6.00 in. and are 0.188 thick. Shear stress is calculated as follows.

A_{shear} = 6.00 in. x 0.188 in. = 1.13 in.^{2}

τ = V/A = 175 lb/1.13 in.^{2} = 155 psi

The allowable shear stress in the plates is 12,247 psi.

Calculate stress in the screws which attach the strap plate to the 1020. Four 0.25 inch diameter screws must react both the actual shear force (175 lb/4 screws = 44 lb) as well as the couple developed by 175 lb over a lever arm of 5 inches.

(175 lb)(5 in.) = 4(2.8 in.)V_{couple} (do not take credit for inner two screws as lever arm is short)

V_{couple} = 78 lb

$V_{lateral\ load}$ =175 lb/4 screws = 44 lb

V_{total} = 78 lb + 44 lb = 122 lb

$\tau = V_{total}/A_{0.25\ in.\ diam.\ screw}$ = 122 lb/0.0269 in.^{2} = 4,535 psi

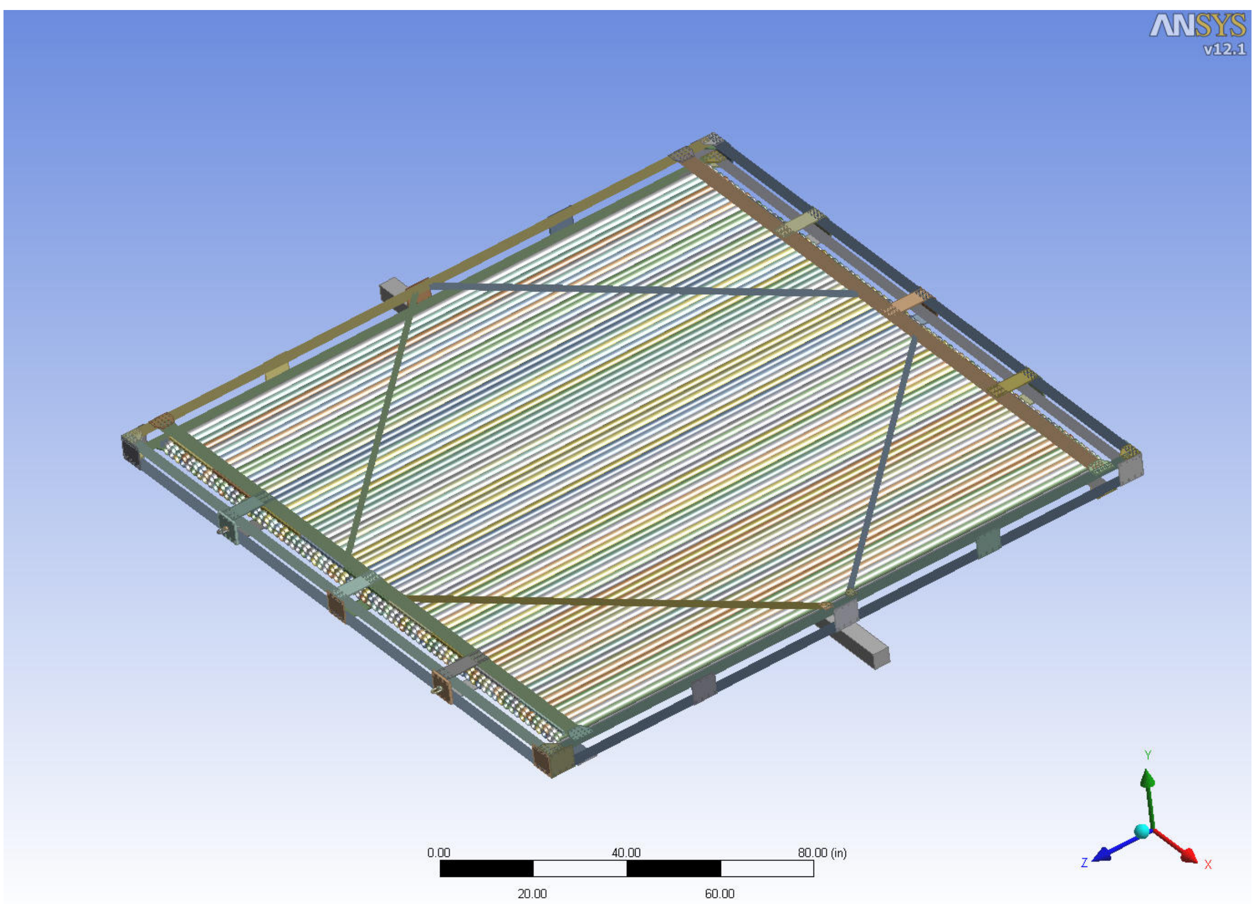
The allowable shear stress in the screws is 17,170 psi. Refer also to Calculation #9. The directions of the two shear forces are 45 degrees apart, which will lower the stress. Additionally, the other three plates inboard of the ends will help carry the shear as well. Shear stress calculated above is conservative.

Frame in vertical position (tube axes perpendicular to floor)

Stresses in the frame are minimal in the vertical position. Loads are well distributed throughout frame, no significant bending moments occur, and stresses are primarily membrane through the frame members. Loads are well distributed from the lifting lug locations. Refer to Calculation #3.

Calculation # 5 – Frame Bending On Uneven Floor A

Calculate bending stress and shear stress for the situation where the frame is supported by a support that runs across the middle of the frame. In other words, frame is set down on a 4” X 4” wood member lying on the floor. The wood member runs across the frame mid-span perpendicular to the tube axis direction.



Attached 1020 information shows the moment of inertia about the weak axis of a 1020 member to be 0.0833 $in.^4$ The tubes are supported at the ends via the scalloped brackets. The bottom 1020 pieces (one on each side) will initially be considered to carry the load. Use the case of a cantilevered beam whose length is 76 inches. Point load is 700 lb/4 or 175 lb.

Moment $_{max}$ = (175 lb)(76in) = 13,300 in-lb

σ_{max} = M c/I = (13,300 in-lb)(0.5in.)/0.0833 $in.^4$ = 79,832 psi

Stress is too high, as yield stress is 35 ksi for 6105-T5 aluminum.

Need to take credit for both top and bottom layers. This will mean that shear must be transmitted effectively between top and bottom layers. Check bending stress for situation where top and bottom 1020 layers participate. Use parallel axis theorem to calculate net moment of inertia ($I_x = I_{xc} + Ad_1^2$).

I_{total} = 2(0.0833 $in.^4$) + 2(0.7914 $in.^2$)(2 $in.)^2$ = 6.5 $in.^4$

σ_{max} = M c/I = (13,300 in-lb)(2.5in.)/6.5 $in.^4$ = 5,115 psi

Bending stress is acceptable since the calculated stress is less than the 19,487 psi allowable tensile stress for the 1020 beams. Reaction load at ends is 175 lb, so shear force of 175 lb must be carried within the frame at the ends. Strap plates are 5.75 in. x 6.00 in. and are 0.188 thick. Shear area is

A_{shear} = 6.00 in. x 0.188 in. = 1.13 $in.^2$

τ = V/A = 175 lb/1.13 $in.^2$ = 155 psi

The allowable shear stress for 6105-T5 is 12,247 psi. Accordingly, this calculated stress is acceptable.

Calculate stress in the screws which attach the strap plate to the 1020. Four 0.25 inch diameter screws must react both the actual shear force as well as the couple developed by 175 lb over a lever arm of 5 inches.

(175lb)(5 in.) = 4(2.8 in.)V_{couple} (do not take credit for inner two screws as lever arm is short)

V_{couple} = 78 lb

$V_{lateral\ load}$ =175 lb/4 screws = 44 lb

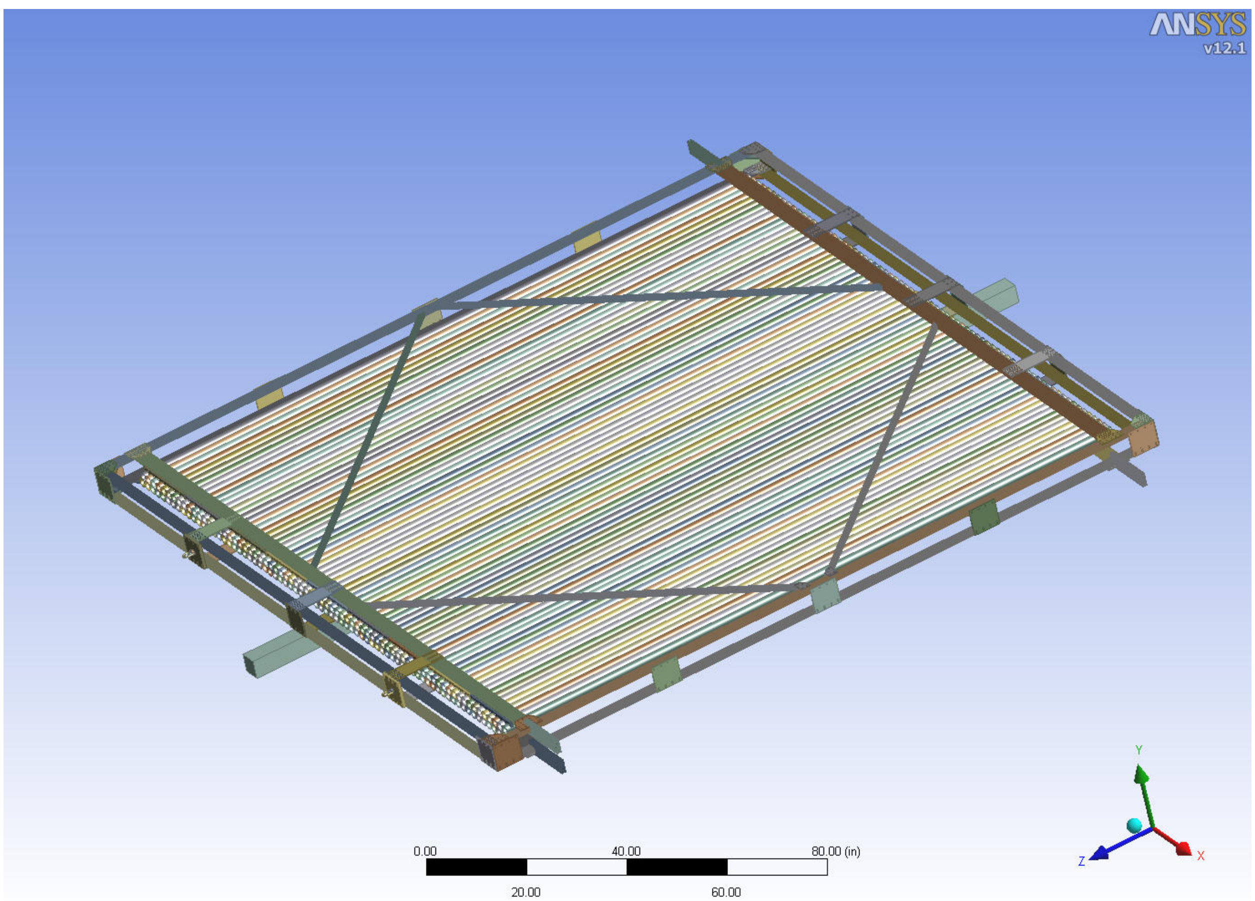
V_{total} = 78 lb + 44 lb = 122 lb

$\tau = V_{total}/A_{0.25\ in.\ diam.\ screw}$ = 122 lb/0.0269 $in.^2$ = 4,535 psi

The fastening hardware is AISI 4037 quenched and tempered steel, according to the 80/20 vendor. The calculated stress is well below the allowable shear stress of 17,170 psi. The directions of the two shear forces are 45 degrees apart, which will lower the stress. Additionally, the other three plates inboard of the ends will help carry the shear as well. Shear stress calculated above is conservative. Refer also to Calculation #9.

Calculation # 6 – Frame Bending On Uneven Floor B

This calculation is similar to Calculation #5 above, but the wood beam placed on the floor runs coincident with the tubes. It supports the frame in the middle, but 90 degrees to the wood floor support in Calculation #5. The frame is square and there are more support members running across the ends so stresses will be lower.

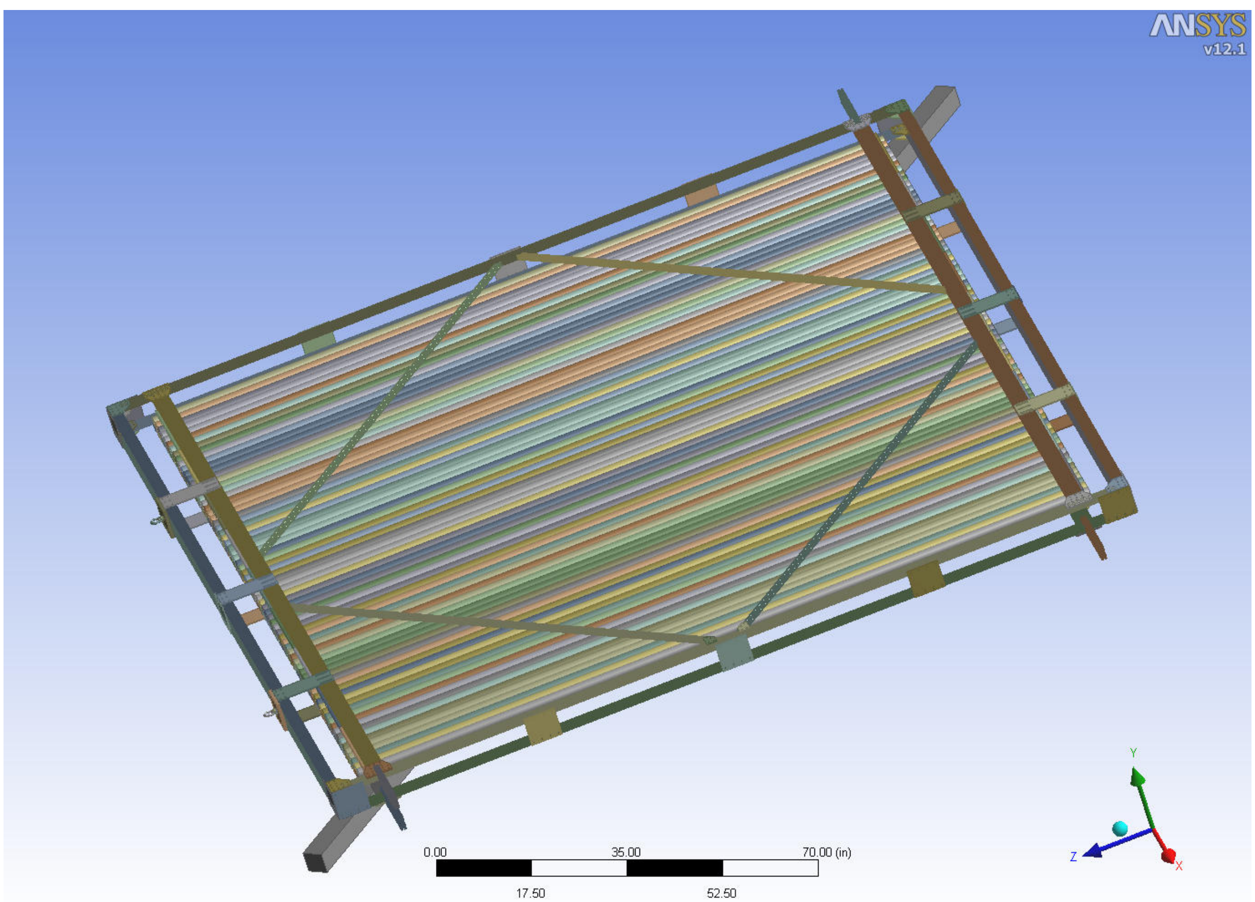


$Moment_{maximum}$ = 13,300 in-lb   (from above, as frame is square)

Frame has a lower layer and an upper layer. Strap plates will connect the upper and lower layers, so that the upper and lower layers can be taken credit for in bending, as in Calculation #5. There is a 1020 and 1030 piece on the bottom, and a 1020 and 1030 piece on top. The effective I for these bottom and top layers is more than for Calculation #5. The maximum moment and c are the same. Thus bending stress will be lower. Shear will be transmitted as in Calculation #5, so shear stress is acceptable. Scalloped pieces were not taken credit for. Also this case involves more of a distributed load along beam, versus a point load at the end for Calculation #5.

Calculation # 7 – Frame Bending on Uneven Floor C

Check bending stress for bending about an axis that runs corner to corner. Frame laid down on floor onto wood beam from Calculation #5 and #6, wherein beam runs from frame corner to frame corner. Use parallel axis theorem again, and use the plate thickness at the corners.



Calculate maximum moment. The area on either side of the wood beam is triangular, with the center of mass 1/3 of the way out from the diagonal bending axis, or 108.2 in./3 or 36 inches.

$\text{Moment}_{maximum}$ = (350 lb)(36 in.) = 12,600 in.-lb

Use parallel axis theorem to calculate net moment of inertia ($I_x = I_{xc} + Ad_1^2$) for the brackets at the frame corners.

$I_{\text{total for brackets at corners}} = \sim 0 \text{ in.}^4 + 8(0.188 \text{ in.})(4.0 \text{ in.})(2.5 \text{ in.})^2 = 37.6 \text{ in.}^4$

$\sigma_{max} = M\,c/I = (12{,}600 \text{ in-lb})(2.5\text{in.})/37.6 \text{ in.}^4 = 838 \text{ psi}$

Bracket material is 6105-T5 material with an allowable shear stress of 12,247 psi. Calculated stress is acceptable.

Check shear stress in screws that attach the eight plates.

$\text{Moment}_{maximum} = (5\text{in.})(4 \text{ plates})F_{plate}$ (summing moments about lower frame surface at brackets)

F_{plate} =630 lb.

Each plate has at least 12 screws. Each side of the plate has six screws. Force per screw is then 630 lb/6 or 105 lb. Screws are ¼”-20, with a shear area of 0.0269 in.^{2} The shear stress in the screw is calculated as follows.

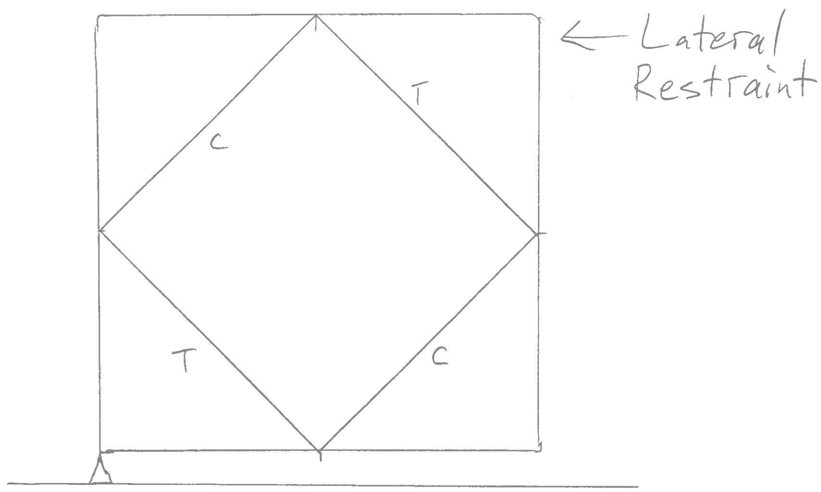
$\tau = V_{total}/A_{0.25 \text{ in. diam. screw}} = 105 \text{ lb}/0.0269 \text{ in.}^2 = 3{,}904 \text{ psi}$

The allowable shear stress for the screws is 17,170 psi, so that the calculated shear stress above is acceptable. Refer also to Calculation #9.

Calculation # 8 – Frame Skewing

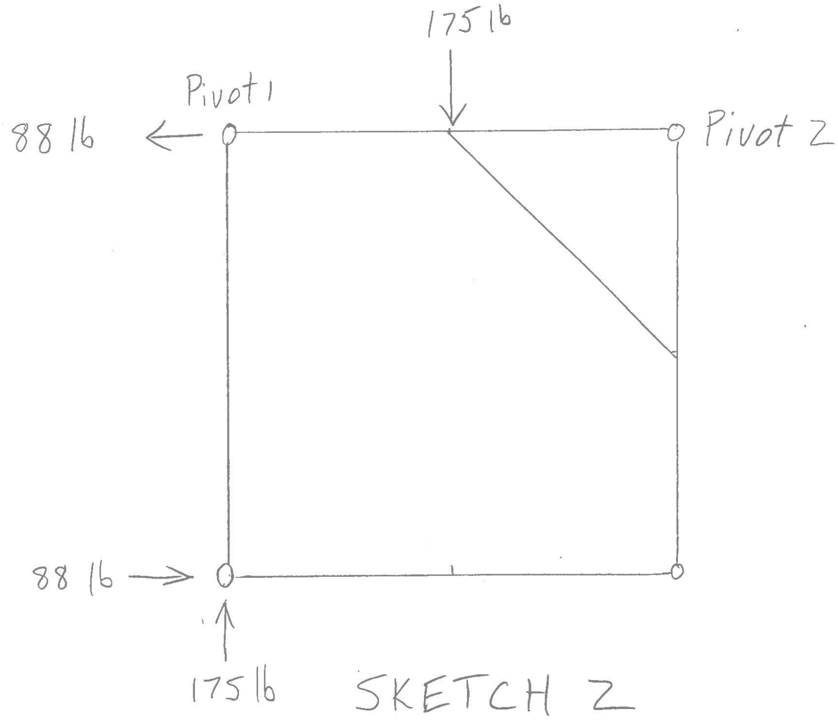
The following calculation will consider frame skewing (i.e. frame tendency to go from a square to a parallelogram shape). This deformation mode is what the four diagonal members are used to prevent. This scenario would cover an event where the frame is lowered onto one corner while providing lateral restraint. The following will calculate the stress in the diagonal, the attachment plate and the screws.

As the frame tries to skew, two of the four top diagonals will be placed in tension, and two in compression. The same holds true for the bottom layer. Only the diagonals placed in tension will be taken credit for since the compressed two could bow. Refer to Sketch 1 below.

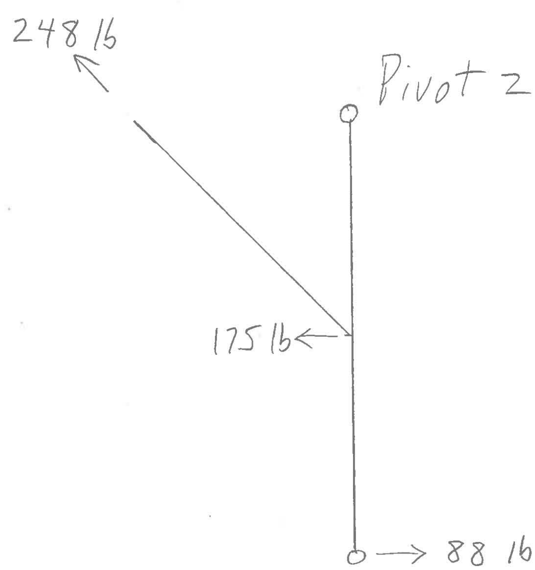


SKETCH 1

The total frame weight is 700 lb. Frame corner connections will be assume to be pinned, with all of the support provided by the diagonals. Half of the load carried by the bottom layer of four diagonals , and half carried by the top layer. Each top layer tensile diagonal then carries 175 lb (700 lb /2 layers is 350 lb per layer, then divided by two for two tensile diagonals is 175 lb per tensile diagonal) . Summing moments about pivot 1 in Sketch 2, $F_{cross\ piece,\ frame}$ is 88 lb. Summing forces about Pivot 2 in Sketch 3, the force in the diagonal is 250 lb. The diagonal is made from 1010 with a cross sectional area of 0.4379 in.^{2}



SKETCH 2



SKETCH 3

σ_{brace} = F/A =250 lb/0.4379 in.^{2} = 571 psi

The bracket attaching the diagonal is 0.188 in. thick with a min. width of 2 in.

$A_{bracket,\ cross\ section}$ = (0.188 in.)(2 in.) = 0.376 in.^{2}

$\sigma_{bracket}$ = F/A = 250 lb/0.376 in.^{2} = 665 psi

The brace and bracket stresses calculated above are acceptable as they are below the 19,487 psi allowable stress.

Bracket is attached with two screws on either side. Shear stress in screws is calculated as follows.

$A_{shear,\ 0.25\ in.\ diam.}$= 0.0269 in.^{2}

$\tau = V_{total}/2A_{0.25\ in.\ diam.\ screw}$ = 250 lb/[2(0.0269 in.^{2})] = 4,647 psi

The calculated shear stress is acceptable, as it is below the allowable fastener shear stress of 17,170 psi. Refer also to Calculation #9.

The same results hold for the other top layer diagonal, as each is assumed to carry 175 lb.

Calculation # 9 – Joining Plate Fastener Strength

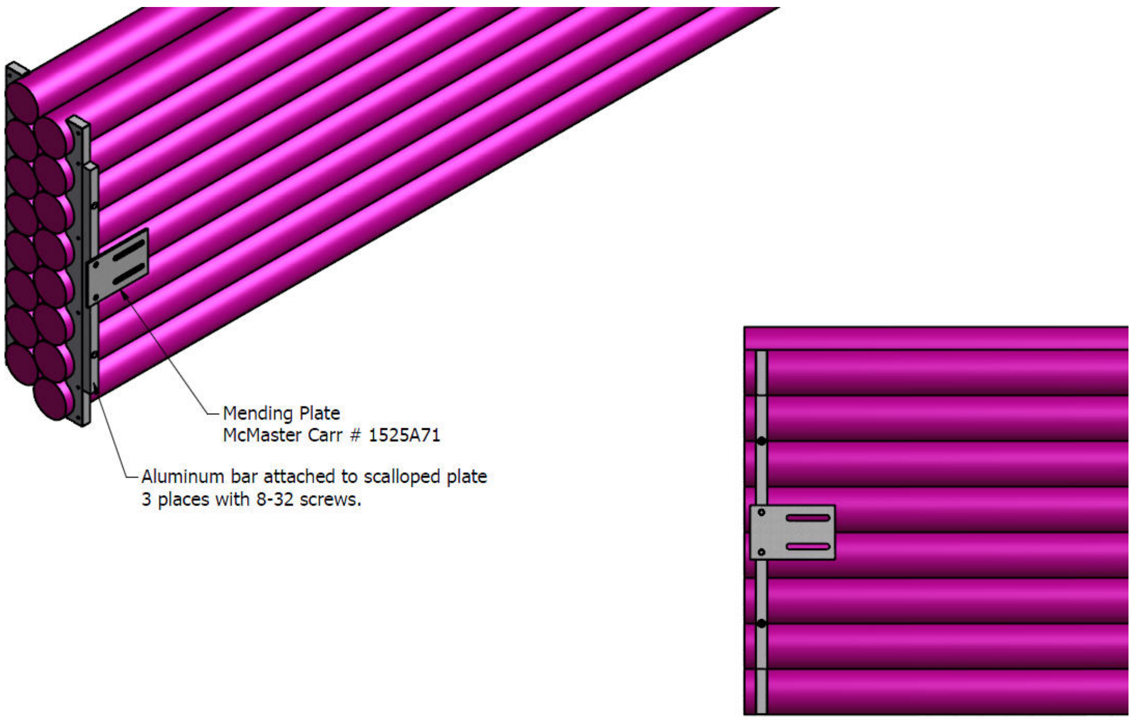
The strength of the fastened connection between joining plates and the 1020 or 1030 members will be evaluated herein. The fasteners which attach the joining plates to the 1020 or 1030 members are ¼"-20 screws. According to the manufacturer, these screws are made from AISI 4037 quenched and tempered steel. These screws go through the joining plates and are threaded into an "economy nut" within the 1020 or 1030 channel. It is difficult to analyze the shear strength (load across fastener) or tensile strength (load along fastener axis) of this connection with respect to the nut pulling out of the extruded part. Optimistically, one would consider the yield strength of the screw and use a reduced allowable shear force or tensile force. The 80/20 manufacturer recommends an allowable shear load of 175 lb per the attached page 155 of their catalog. The shear area of a ¼"-20 screw is 0.0269 in.^{2}. The allowable shear stress could be calculated using the vendor load as,

$\tau_{allowable} = V_{vendor\ allowable} / A_{shear}$ = 175 lb/0.0269 in.^{2} = 6,505 psi

This pertains to shear loading of the screw. This stress will be treated as the maximum allowable shear stress in the ¼"-20 screws for the frame analysis. This stress will also be treated as the maximum allowable tensile stress for the screws for the frame analysis.

Calculation #10 – Load Transmission Between Tubes and Frame for 4X and 4Y

The following calculation addresses the Prop Tube assembly hanging in the x or y orientation for conducting experiments. The 4Y orientation configures the tubes so that they are parallel to the floor, while the 4x orientation places tubes with their axes perpendicular to the floor. Long strips with scallops on either end of the tube array secure the tubes as shown below. Each strip is scalloped so that each tube is nested in a scallop on either side of the tube. This occurs at both ends of the tube. The scalloped parts are then secured to the aluminum strip with three 8-32 screws. A mending plate is then secured to the aluminum spacer bar with two ¼-20 screws.



Extra Support for 4Y Prop Tube Modules

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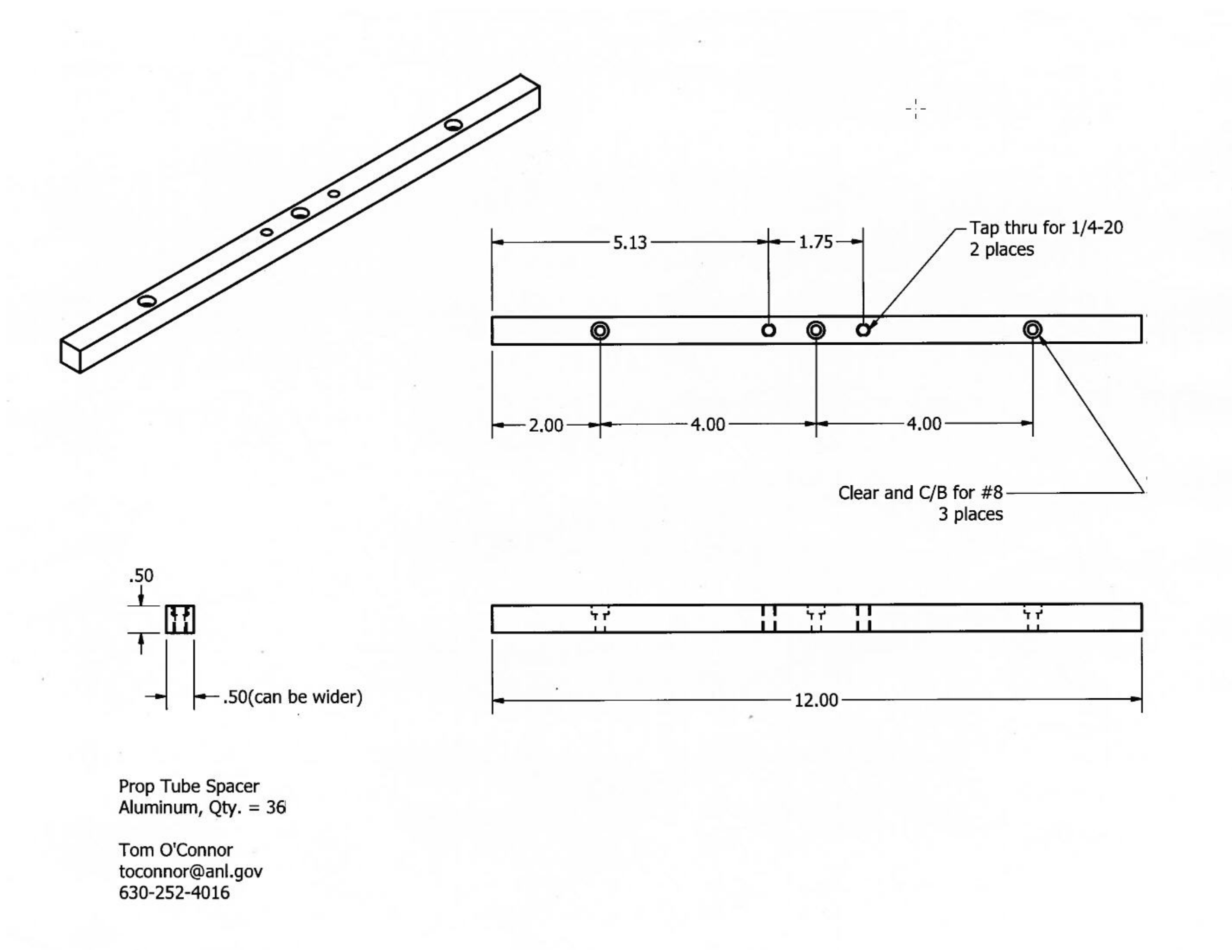


The 4Y orientation is analyzed as follows. Each tube weighs 3.11 lb per Calculation #1, and 10% was added for glue in Calculation #2. Thus tube weight is 3.42 lb. Use 3.5 lb for this calculation. Estimate 4 lb for 0.5 inch thick aluminum scalloped bar. Calculate the shear stress in the three 8-32 screws as follows.

$A_{shear,\ 8\text{-}32\ screw}$ = 0.012 in.^{2}

τ = V/A = [(8)(3.5 lb)/2 + 4 lb] / 3(0.012 in.^{2})

= 500 psi

The yield strength of stainless steel screws is taken as 30,000 psi, and an allowable stress of 15,000 psi will be used. The shear allowable will be 7,500 psi. Thus substantial margin exists for the 8-32 screws.

These loads are then transmitted through the 0.1 inch thick steel mending plate. The mending plate is secured to the strip with two ¼-20 screws.

$A_{shear,\ ¼\text{-}20\ screw}$ = 0.0269 in.^{2}

$\tau = V/A = [(8)(3.5 \text{ lb}) + 4 \text{ lb}] / 2(0.0269 \text{ in.}^2)$

$= 595 \text{ psi}$

Again, substantial margin exists.

The total number of these mending plates is 36. Nine are placed down each side, with four sides total for 36. Consequently, the load of the tubes is distributed uniformly into the 1030 frame. The cross sectional area for the 1030 frame member is 1.15 in.^{2} per literature from vendor (see end of this report). The stress is in the 1030 member is calculated as follows.

$\sigma = F/A = ((9) [(8)(3.5 \text{ lb})/2 + 4 \text{ lb}]) / (1.15 \text{ in.}^2) = 162 \text{ lb}/ 1.15 \text{ in.}^2$

$= 141 \text{ psi}$

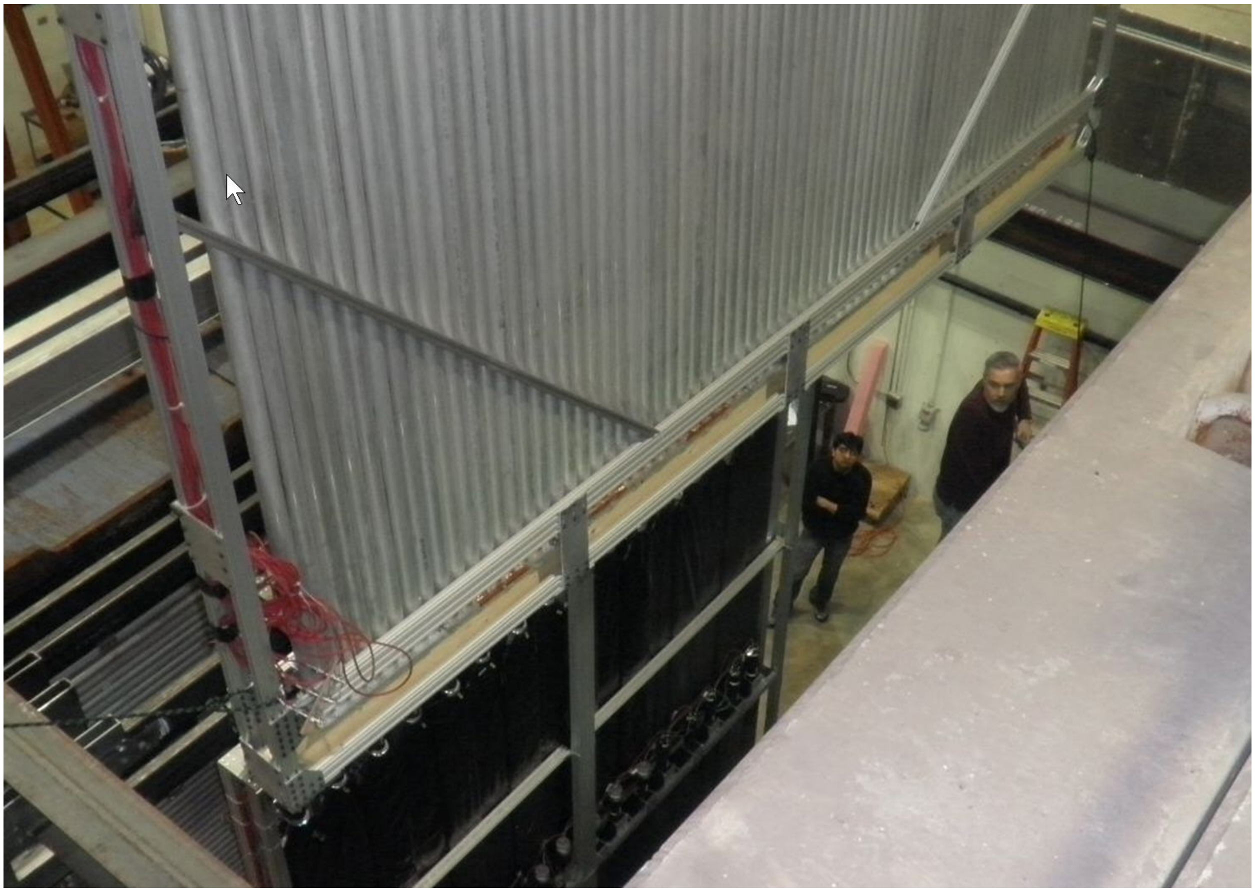
The allowable stress of the 1030 member is 19,487 psi, as found at the beginning of this document. Substantial margin exists.

The load from the 1030 member is transmitted to the outer 1020 members via joining plates along the length of the 1030 beam (three locations), and a joining plate at each end of the 1030 beam. The shear load of each joining screw is 175 lb, per above. Again, substantial margin exists given the number of screws joining the 1030 member to the 1020 members.

The following calculation addresses the Prop Tube assembly hanging in the x or y orientation for conducting experiments. The 4Y orientation configures the tubes so that they are parallel to the floor, while the 4x orientation places tubes with their axes perpendicular to the floor. Long strips with scallops on either side of the tube array secure the tubes as shown below. at each end is scalloped so that each tube is nested in a scallop on either side of the tube. This occurs at both ends of the tube. The scalloped parts are then secured to the G-10 strip with three 8-32 screws. A mending plate is then secured to the G-10 bar.

The 4X orientation (tube axis vertical) is analyzed as follows. The tubes are glued to each other and to the scalloped strips. The tube loads will be transmitted through the glue to the scalloped strips and then into the 80/20 frame as before. Loads will be transmitted to the 1030 and 1020 members given the mending and strap plates. Additionally, a block of wood is placed underneath the tubes. This block is used to further prevent tubes from sliding down, and also to help align the ends of the tubes during assembly. Loads from the tubes are also transmitted to this wood piece and out to strapping plates that join the upper 80/20 frame to the lower frame as shown below. Wood beam is secured to the strapping plate with screws to hold the beam in place.


GLASS



Five plates are located under the wood beam. Each plate has a total of eight screws attaching the plate to the 1020 sections, four on each side. The screws are ¼ -20 screws. Calculate the tensile load in each screw as follows.

F_{screw} = [(144 tubes)(3.5 lb/tube)] / [(5 plates)(8 screws/plate)]

= 504 lb / 40 screws

= 12 lb / screw

The 80/20 vendor does not have data for allowable screw loading wherein the screw is pulled straight out of the extrusion. The above stress appears to be acceptable, but a simple pull out test may be warranted.

The five plates create four spans wherein the wood beam must support the tubes between strapping plates. The load per span is estimated as 504 lb/4 or 126 lb per span. The wood beam is pine and is a 2 inch x 6 inch beam, which measures 5.5 inches x 1.5 inches. The bending stress and shear stress in the beam are calculated as follows.

$I = bh^3 / 12 = (1.5 \text{ in.})(5.5 \text{ in.})^3 / 12 = 20.8 \text{ in.}^3$

$A = (1.5 \text{ in.})(5.5 \text{ in.}) = 8.25 \text{ in.}^2$

The moment will be calculated for the case of a simply supported beam, with a distributed load.

L= 156 in. / 4 = 39 in.

w = 126 lb / 39 in. = 3.2 lb / in.

$M = wl^2 / 8 = 614$ in-lb

$\sigma_b = Mc/I = (614 \text{ in-lb})(2.75 \text{ in.}) / 20.8 \text{ in.}^3$

$\sigma_b = 81$ psi

V = wl/2 = 63 lb

$\tau = V/A = 63 \text{ lb} / 8.25 \text{ in.}^2$

$\tau = 7.6$ psi

The stresses are acceptable.

The glue used between the tubes, and tubes to scalloped strips, is 3M non-sag epoxy 460 DP. The strength of this epoxy is significant, as noted below. This fact, combined with the contact area involved in the 4X and 4Y assemblies, results in substantial load carrying capability.

3M™ Scotch-Weld™ Epoxy Adhesive DP-460 EG

Product Description

3M™ Scotch-Weld™ Epoxy Adhesive DP-460 EG is designed to have lower outgassing and lower ionics than 3M™ Scotch-Weld™ Epoxy Adhesive DP-460. Laboratory testing has shown that 3M™ Scotch-Weld™ Epoxy Adhesive DP-460 EG's curing and adhesive performance to be comparable to 3M™ Scotch-Weld™ Epoxy Adhesive DP-460.

Application Ideas

- Hard Disk Drive Assembly
- Spindle Motor Assembly
- Magnet Bonding
- E-Block Assembly
- Bearing Cartridge Assembly
- Potting
- Rigidizing

Key Features

- Curing and bonding performance comparable to 3M™ Scotch-Weld™ Epoxy Adhesive DP-460.
- Total outgassing < 1000 μg/g (via GC/MS, 85°C for 3 hours).
- Siloxane outgassing ≤ 5 μg/g (via GC/MS, 85°C for 3 hours).
- Lower chloride ion content than standard epoxies.

Typical Physical Properties

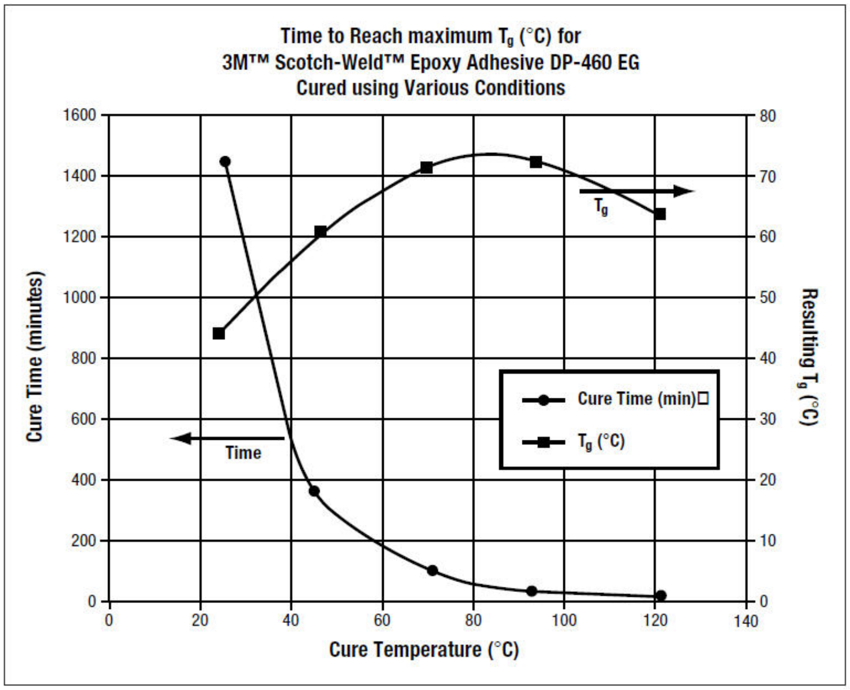
Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

Product		3M™ Scotch-Weld™ Epoxy Adhesive DP-460 EG
Viscosity (at 72°F [23°C])	Base Accelerator Mixed	25,000 - 45,000 cps 8,000 - 14,000 cps 15,000 - 25,000 cps
Base Resin	Base Accelerator	Epoxy Amine
Color	Base Accelerator	White Amber
Net Weight (lb/gallon)	Base Accelerator	9.4 9.0
Mix Ratio (B:A)	Volume Weight	2:1 2:0 : 0.96
Worklife (72°F [23°C])		110 minutes

Curing

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

This adhesive will cure in 24 hours at room temperature. Heating will accelerate the cure and can result in a higher T_g than room temperature curing yields. Curing data is shown in the figure below.



Note: If the adhesive has become grainy or lumpy in appearance when dispensed, this may be due to crystallization of the adhesive. This can be corrected by heating the adhesive in the syringe to 120°F (49°C) for 30 minutes, then allowing the adhesive to cool before dispensing.

3M™ Scotch-Weld™ Epoxy Adhesive DP-460 EG

Typical Performance Characteristics[1]

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.

Shear and Peel Strength vs. Cure Temperature / Time

	72°F (23°C) 24 hours	120°F (49°C) 270 minutes	160°F (71°C) 90 minutes	200°F (93°C) 30 minutes	250°F (121°C) 10 minutes
Overlap Shear[2] (lbf/in^2) (ASTM D-1002-72)	> 5000	> 5000	> 5500	> 5500	> 5500
T-Peel[3] (lbf/in) (ASTM D1876-61T)	60[4]	59[4]	43[4]	39[5]	45[5]

1 - See Technical Data Sheet 3M™ Scotch-Weld™ Epoxy Adhesive DP-460 for additional typical performance characteristics.

2 - 0.060 inch thick, etched aluminum pulled at 0.10 inches/minute.

3 - 0.032 inch thick, anodized aluminum pulled at 20 inches/minute.

4 - Cohesive failure mode.

5 - Adhesive failure mode.

Storage and Shelf Life

Storage: Store 3M™ Scotch-Weld™ Epoxy Adhesive DP-460 EG at 60-80°F (15-27°C) or refrigerate for maximum shelf life.

Shelf Life: 3M™ Scotch-Weld™ Epoxy Adhesive DP-460 EG has a shelf life of 15 months in its original container.

3M™ Scotch-Weld™ Epoxy Adhesive DP-460 EG

Certification/Recognition

MSDS: Refer to Product Label and Material Safety Data Sheet for Health and Safety Information before using this product. For additional health and safety information, call 1-800-364-3577 or (651) 737-6501.

TSCA: This product is defined as an article under the Toxic Substances Control Act and therefore, it is exempt from inventory listing requirements.

RoHs Complaint/REACH Compliant: This product complies with the European Union's "Restriction of Hazardous Substances" (RoHs) initiative and with European REACH regulations 2002/95/EC and 2005/618/EC.

For Additional Information

To request additional product information or to arrange for sales assistance, call toll free 1-800-251-8634. Address correspondence to: 3M, Electronics Markets Materials Division, 3M Center, Building 225-3S-06, St. Paul, MN 55144-1000. Our fax number is 651-778-4244 or 1-877-369-2923. In Canada, phone: 1-800-364-3577. In Puerto Rico, phone: 1-787-750-3000. In Mexico, phone: 52-70-04-00.

Important Notice

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Warranty; Limited Remedy; Limited Liability.

This product will be free from defects in material and manufacture at the time of purchase. **3M MAKES NO OTHER WARRANTIES INCLUDING, BUT NOT LIMITED TO, ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.** If this product is defective within the warranty period stated above, your exclusive remedy shall be, at 3M's option, to replace or repair the 3M product or refund the purchase price of the 3M product. **Except where prohibited by law, 3M will not be liable for any indirect, special, incidental or consequential loss or damage arising from this 3M product, regardless of the legal theory asserted.**

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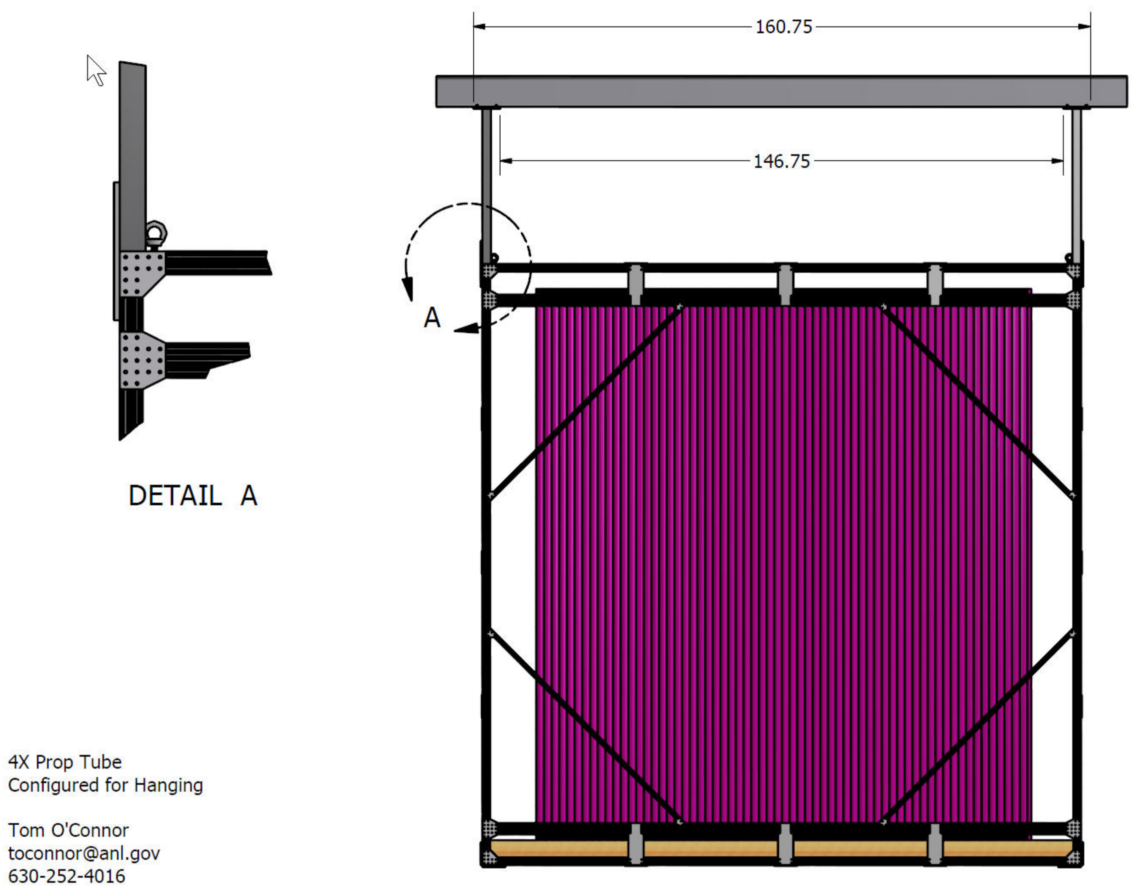
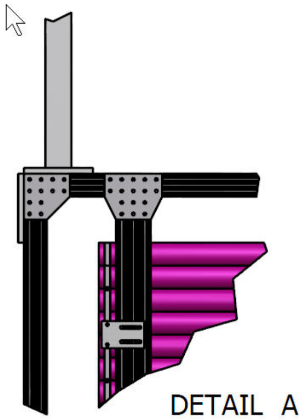
www.3M.com/electronics

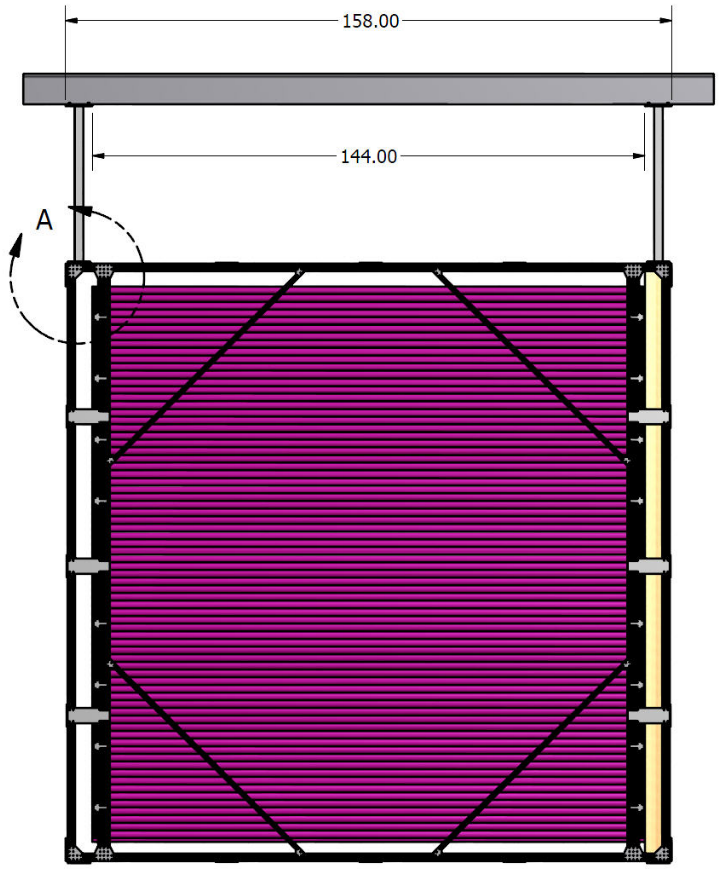
78-6900-9832-8

Calculation #11 – Lifting/Hanging Framework Attached to 4X and 4Y Frames

The lifting apparatus has been revised. The hanging apparatus is detailed below per Tom O’Connor.





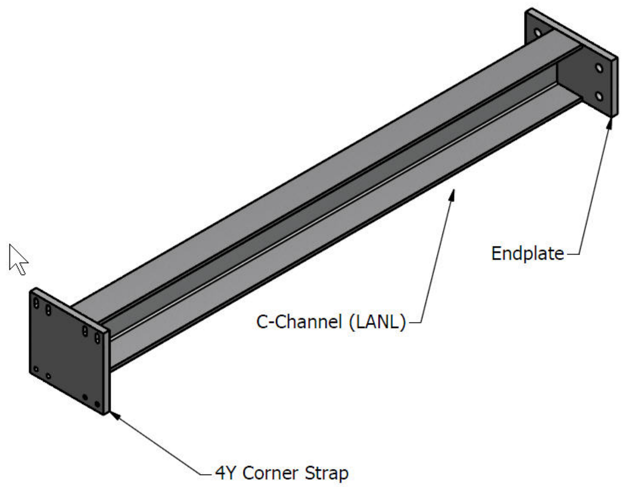


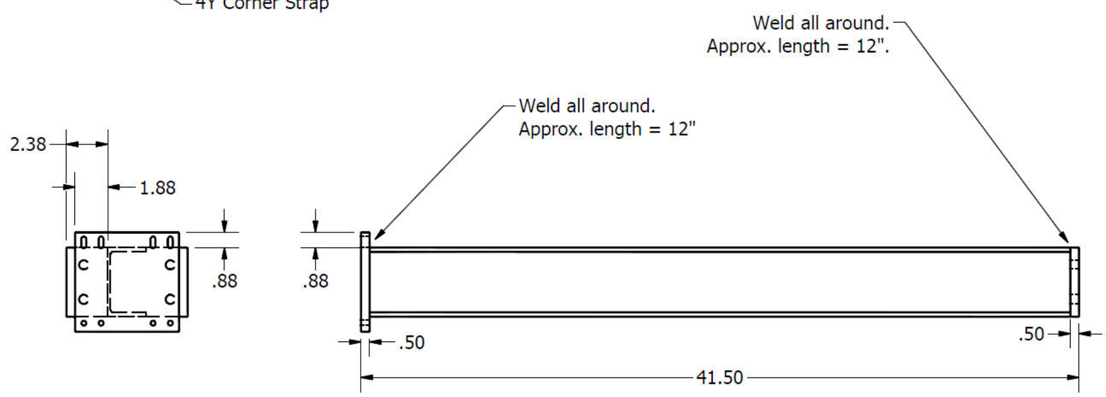
4Y PropTube
Configured for Hanging

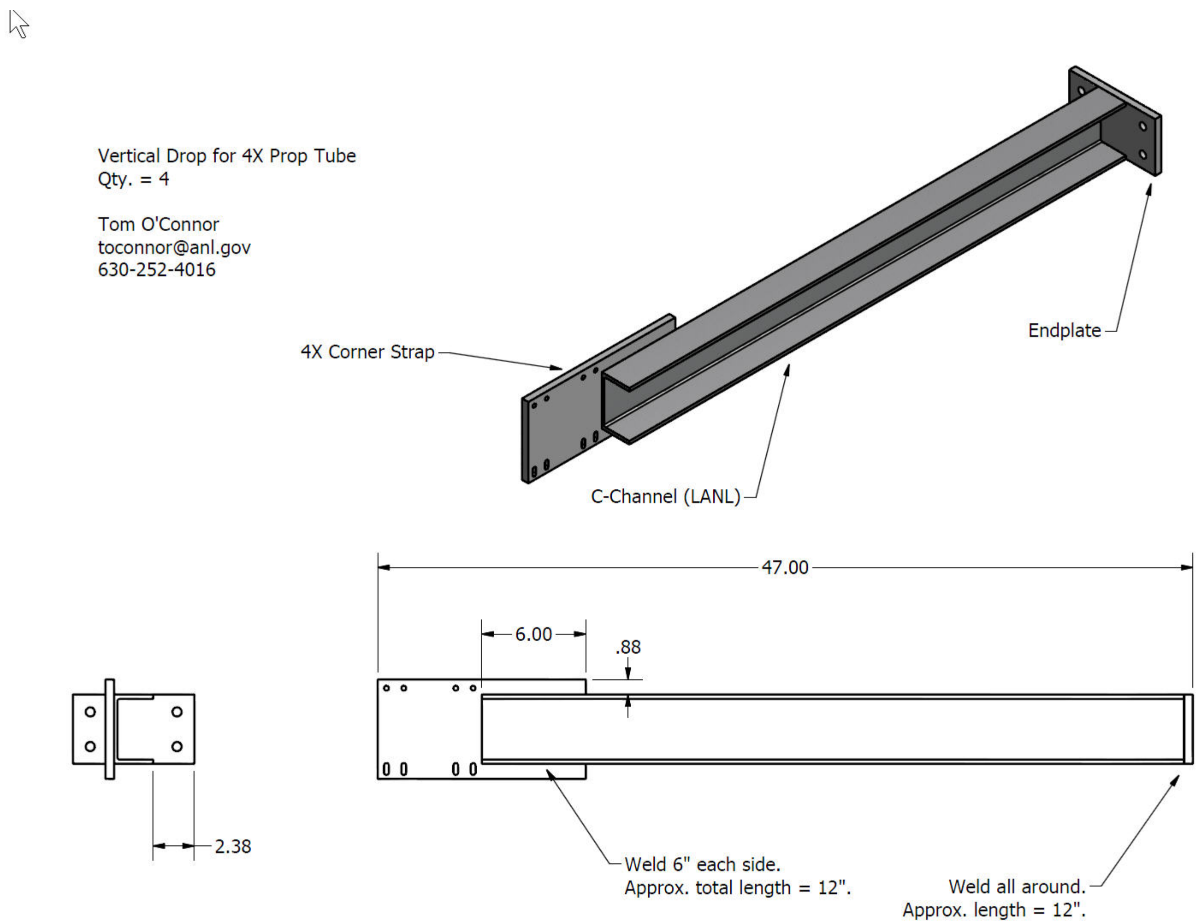
Tom O'Connor
toconnor@anl.gov
630-252-4016

Vertical Drop for 4Y Prop Tube
Qty. = 4

Tom O'Connor
toconnor@anl.gov
630-252-4016







The 4X configuration will be considered first (tube axis perpendicular to the floor). The total frame weight without the added hanging frame is 700 lb, per Calculation #2. The I beam at the top will be analyzed first. It is an S8 x 6.35 aluminum beam. To be conservative, the hook would be located above the I beam, mid-span, so that a concentrated load would exist mid span. The I beam will be analyzed as a beam, simply supported at the end with a concentrated load in the middle.

First calculate weight of added lifting frame.

$Wt_{\text{lifting frame}}$ = (6.35 lb/ft)(16.5 ft) + 2[(3.5 ft)(4 lb/ft) + 2.6 lb]

= 105 lb + 33.2 lb

= 138.2 lb

$M_{\text{mid span}} = FL/4$

F = 700 lb + 138.2 lb = 838.2 lb

L = 150 in.

$M_{mid\ span}$ = FL/4 = (838.2 lb)(150 in.)/4 = 31,433 in-lb

σ = Mc/I = (31,433 in-lb)(4 in.) / 57.6 in.^{4}

c = 4 in.

A = 5.41 in.^{2}

I = 57.6 in.^{4}

σ = 2,183 psi

τ = V/A = (838.2 lb/2) / 5.41 in.^{2}

= 78 psi

The allowable for 6061-T6 aluminum will be taken as 1/3 of yield to provide a factor of safety of three for lifting components. Allowable is then 40,000 psi/3 or 13,333 psi. Substantial margin exists.

Screws attach the end plates to the I beam. The end plates are 0.5 inches thick, so that sufficient thickness exists to prevent tear out. The I beam flange is 7/16 in. thick and also provides sufficient thickness to prevent tearout. Four ½-13 screws attach the end plate to the I beam. Stainless steel screws will be assumed, with a yield strength of 30,000 psi. Use a factor of safety of three to yield for lifting. Thus the screw allowable will be 10,000 psi.

$A_{t,\ 1/2\text{-}13}$ = 0.1419 in.^{2}

σ = F/A = (838.2 lb/2) / ((4)(0.1419 in.^{2}))

= 1,480 psi

Substantial margin exists.

The end plates are attached to the c channel with a fillet weld as shown above. The length will be taken as 12 inches, and a weld size of 3/16 will be used. The throat thickness is then 0.132 in. The weld area is then,

A_{weld} = (12 in.)(0.132 in.) = 1.58 in.^{2}

τ_{weld} = V/A = (838.2 lb/2) / 1.58 in.^{2}

= 265 psi

The filler metal is taken as ER4043, with an allowable stress of 5,900 psi per the Aluminum Design Manual, Part VI, Table 6-2, 2010. Substantial margin exists.

The area of the c channel is taken as 2.12 in.^{2}. The tensile stress in the c channel is then calculated as,

σ = F/A = (838.2 lb/2) / 2.12 in.^{2}

σ = 197 psi

C channel material taken as 6061-T6 with a yield strength of 40,000 psi. Use a factor of safety to yield of three for lifting. Allowable is then 13,333 psi. Substantial margin exists.

The lower end of the c channel is welded to the corner strap plate. The weld length, fillet size and material are taken to be the same as for the top of the c channel. Thus, stress will be same as for weld at top of c channel. Again, substantial margin exists.

The corner strap plate is connected to the tube frame via eight ¼ -20 screws. Four screws (two holes plus two slots) are inserted into tapped holes, and the four remaining screws (two holes and two slots) are anchored via t-nuts. Calculate shear stress in the screws as follows.

$A_{shear,\ ¼\text{-}20}$ = 0.0269 in.^{2}

$A_{tensile,\ ¼\text{-}20}$ = 0.0318 in.^{2}

τ = V/A = (838.2 lb/2)/((8)(0.0269 in.^{2}))

= 1,947 psi

V/screw = (838.2 lb /2) / 8 = 52.4 lb / screw

Assume stainless steel screws, yield strength of 30,000 psi, with an allowable tensile strength of 10,000 psi (factor of safety of 3). The shear allowable is then 5,000 psi, and substantial margin exists. Additionally, the allowable shear load for ¼-20 screws supplied by 80/20 is 175 lb per Calculation #9. Per Tom O'Connor 4 of the eight screws are threaded into tapped holes in the extrusion while the other four are attached via the 80/20 nuts. Sufficient engagement in tapped holes should be checked.

The 4Y configuration only differs from the 4X configuration in the connection at the bottom of the c channel. The weld area between the c channel and the strap plate is taken as the same as for the 4X configuration since the weld length is the same at 12 inches. Thus the weld stress is acceptable. Eight ¼-20 screws again connect the aforementioned strap plate to the tube frame. These screws are loaded in tension for the 4Y versus in shear for the 4X. Four of these screws are tapped into the 80/20 members and four are attached via 80/20 nuts.

σ = F/A_{total} = (838.2 lb/2)/[8(0.0318 in.^{2})]

= 1,647 psi

F/screw = (838.2 lb/2)/8 = 52.4 lb

Per Tom O'Connor 4 of the eight screws are threaded into tapped holes in the extrusion while the other four are attached via the 80/20 nuts. Assume stainless steel screws, yield strength of 30,000 psi, with an allowable tensile strength of 10,000 psi (factor of safety of 3). Substantial margin exists in the screw. **The allowable tensile load for 80/20 fasteners and nuts is not listed. One must be concerned with nuts pulling out of the extrusion. A test may be warranted. Sufficient engagement in tapped holes should be checked.**

The situation wherein the frame is flat on the floor with lifting frame attached, and the frame is picked up with rigging attached to I beam will be considered. This scenario creates a substantial moment at the 4X and 4Y frames where the lifting frame attaches. First estimate force at I beam to lift frame, by summing moments at bottom of frame where it would pivot on floor as it is being lifted.

$F_{\text{at I-beam}}$ (210 in.) = (700 lb)(160 in/2) + (125 lb)(195 in.)

$F_{\text{at I-beam}}$ = 382 lb

Calculate the moment at this location for 4X or 4Y frames, by summing moments at the intersection point between prop tube frame and lifting frame.

$M_{\text{at lifting frame to prop tube frame}}$ = (382 lb/2)(50 in) – (125 lb/2)(18 in.) = 8,425 in-lb

This moment must be reacted by eight screws in shear for 4X frame. Calculate the shear load in these eight screws, wherein each screw is 3 inches from the plate center for rotation.

8,425 in-lb = (3 in.)(8)(V_{screw})

V_{screw} = 351 lb

As noted above, Tom O'Connor stated that four of these screws are run into tapped holes in the extrusion while four screws use the 80/20 nuts. The allowable shear force for the 80/20 screws is 175 lb**. CALCULATED APPLIED FORCE IS TWO TIMES THE ALLOWABLE VALUE. UNSAFE.**

The shear stress in a the screw is calculated as,

τ_{screw} = V/A = 351 lb / 0.0269 in.^{2} = 13,048 in.^{2}

This is well above the allowable shear stress used above of 5,000 psi. If stronger screws are used allowable is higher and may be acceptable for these screws only, not the other four.

The 8,425 in-lb moment must be reacted in tension/compression for the 4Y frame. Four screws on one side of the plate will be placed in tension. Calculate tension in screws on one side of the plate, by summing moment about other side of plate.

8,425 in-lb = 4(F_{screw})(5 in.)

F_{screw} = 422 lb

Again four screws are placed into tapped holes in the extrusion and four screws utilize the 80/20 nuts. **The allowable tensile load for 80/20 fasteners and nuts is not listed. One must be concerned with nuts pulling out of the extrusion. A test may be warranted. Sufficient engagement in tapped holes should be checked.**

Calculate the tensile stress in the screws.

$\sigma = F/A_{\text{tensile, ¼-20 screw}} = 422 \text{ lb} / 0.0318 \text{ in.}^2$

$\sigma = 13{,}271$ psi

The allowable tensile stress for stainless steel with a factor of safety of three is 10,000 psi.

THE 4X AND 4Y FRAMES (PLACED FLAT ON FLOOR) SHOULD NOT BE LIFTED BY THE I BEAMS OFF OF THE FLOOR. A STECILED NOTE ON FRAME MAY BE WARRANTED.

Why Do We Use 6105-T5 Aluminum Alloy?

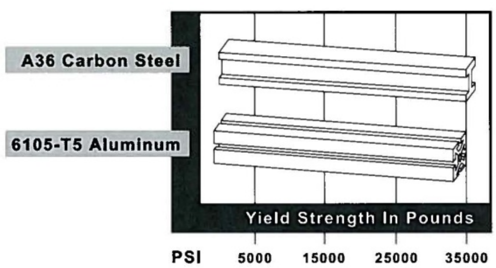
Aluminum Profile Alloys: Number and Characteristics	Tensile Strength - ksi*			
	Ultimate		Yield	
	minimum	maximum	minimum	maximum
6105-T5 (80/20's Alloy)	38.00	••	35.00	••
6063-T6	30.00	••	25.00	••

*Figures based on material thickness of 0.125 to 1.00"
From The Aluminum Extrusion Manual, published by The Aluminum Association and the Aluminum Extruders Council.

All of 80/20's T-slotted profiles feature the 6105-T5 alloy. An aluminum extrusion alloy is a mixed metal that includes other elements such as copper, magnesium, iron, silicon or zinc. Certain properties such as strength, machinability and corrosion resistance are influenced by the choice of alloy and temper. **Alloy 6105 with a T5 temper, chosen by 80/20, has better machinability and strength than 6063-T6.**

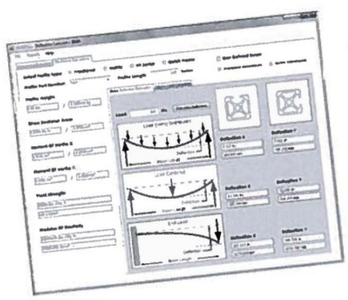
6105 ↑ **Alloy** **T5** ↑ **Temper**

Material Strength Specifications



Minimum Yield Strength In Pounds

- 80/20®'s 6105-T5 alloy yield strength of 35,000 psi compares to A36 carbon steel's yield strength of 36,000 psi.
- Volume for volume, aluminum weighs about 1/3 as much as iron, steel, copper, or brass.



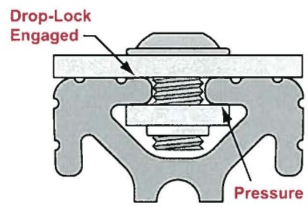
Deflection CalculatorX™

Download 80/20®'s Deflection CalculatorX™, the profile strength calculator, at www.8020.net/Design-Tools-1.asp

Fractional

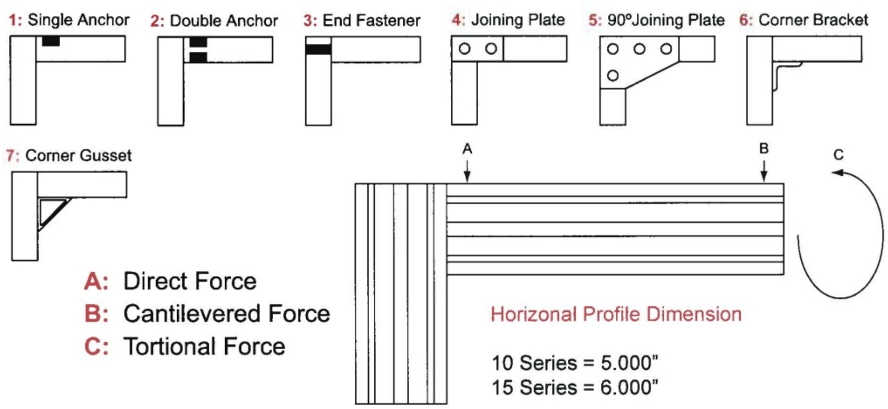
Torque Specifications

- See table below for the amount of torque in foot-lbs. required to activate the 2° drop-lock feature for T-slotted profiles
- Nut and bolt combination is pre-loaded when tightened to the minimum torque rating
- When properly tightened, fasteners will not loosen even under heavy vibration



Part Number	Fastener Description	Tested Profile	Minimum Ft-lbs. Torque	Maximum Ft-lbs. Torque
3320	5/16-18 x 11/16 Flanged BHSCS & Economy T-Nut	1515	10.00	15.00
3325	5/16-18 x 3/4 Economy T-Slot Stud, Washer & Hex Nut	1515	30.00	40.00
3360	15 Series Anchor Fastener Assembly	1515-Lite	10.00	28.00
3380	15 Series End Fastener Assembly	1515-Lite	10.00	22.00
3321	1/4-20 x 1/2 Flanged BHSCS & Economy T-Nut	1010	4.00	6.00
3395	10 Series Anchor Fastener Assembly	1010	3.00	17.00
3381	10 Series End Fastener Assembly	1010	4.00	17.00

Fastener Application Tests



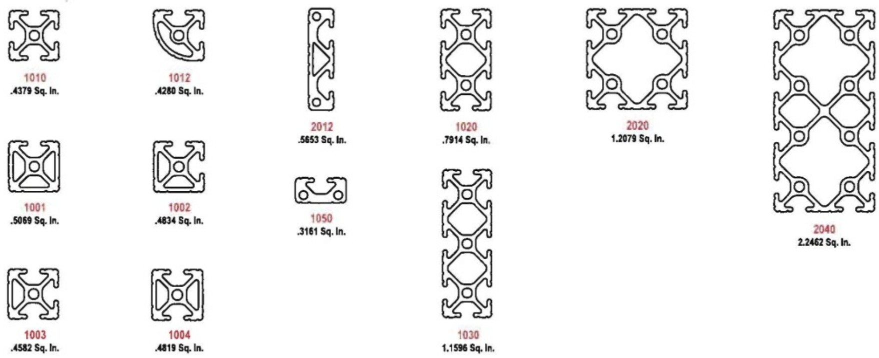
Fastener	1010 Profile			1515-Lite Profile			1515 Profile		
	A (lbs.)	B (lbs.)	C (Inch-lbs.)	A (lbs.)	B (lbs.)	C (Inch-lbs.)	A (lbs.)	B (lbs.)	C (Inch-lbs.)
1	500	250	180	950	625	540	950	1,000	700
2	900	250	260	1,200	700	1,150	1,200	1,200	2,000
3	450	200	325	1,000	500	680	1,000	820	1,150
4	175	50	400	225	200	1,000	225	200	1,100
5	175	50	500	250	200	1,120	250	200	1,260
6	325	75	180	375	225	500	575	225	500
7	325	220	260	375	750	500	575	750	500

Note: Plates, brackets and gussets were attached with 80/20® recommended bolt kits. Fasteners were tightened according to 80/20® torque specifications found at the top of the page.

Test results reflect the connection failure point. Loads at or above these points are not recommended.

80/20® Inc.
The Industrial Erector Set®
THE STANDARD

10 Series Profile Material Specifications



Compatibility Code*: 6-10

Part No.	1010	1001	1002	1003	1004	1012
Material	6105-T5 Aluminum					
Finish	Clear Anodize #204-R1					
Weight Per Foot	.5097 Lbs.	.5900 Lbs.	.5627 Lbs.	.5333 Lbs.	.5609 Lbs.	.4982 Lbs.
Stock Length **	97", 145", 242"	145" or 242"	145" or 242"	145" or 242"	145" or 242"	145" or 242"
Moment of Inertia	IX=.0442"^{4} IY=.0442"^{4}	IX=.0542"^{4} IY=.0493"^{4}	IX=.0492"^{4} IY=.0492"^{4}	IX=.0491"^{4} IY=.0441"^{4}	IX=.0541"^{4} IY=.0443"^{4}	IX=.0400"^{4} IY=.0400"^{4}
Estimated Area	.4379 Sq. In.	.5069 Sq. In.	.4834 Sq. In.	.4582 Sq. In.	.4819 Sq. In.	.4280 Sq. In.
Modulus of Elasticity	10,200,000 Lbs./Sq. In.					

Part No.	1050	2012	1020	1030	2020	2040
Material	6105-T5 Aluminum					
Finish	Clear Anodize #204-R1					
Weight Per Foot	.3679 Lbs.	.6580 Lbs.	.9212 Lbs.	1.3498 Lbs.	1.4060 Lbs.	2.6146 Lbs.
Stock Length **	145"	145"	97", 145", 242"	145" or 242"	145" or 242"	145" or 242"
Moment of Inertia	IX=.0074"^{4} IY=.0323"^{4}	IX=.2253"^{4} IY=.0146"^{4}	IX=.3078"^{4} IY=.0833"^{4}	IX=.9711"^{4} IY=.1238"^{4}	IX=.5509"^{4} IY=.5509"^{4}	IX=3.5168"^{4} IY=1.0513"^{4}
Estimated Area	.3161 Sq. In.	.5653 Sq. In.	.7914 Sq. In.	1.1596 Sq. In.	1.2079 Sq. In.	2.2462 Sq. In.
Modulus of Elasticity	10,200,000 Lbs./Sq. In.					

* See Compatibility Code information on page 152.
** For profile lengths other than stock length refer to page 563 for profile cut to length services.